UDC 551.576.2:551.501.776:551.507.362.2(084.1)(4)(261)

Comparison of Mean Cloud Cover Obtained By Satellite Photographs and Ground-Based Observations Over Europe and the Atlantic

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ABSTRACT—An important field of weather observation is the statement of cloud cover of the sky. Clouds not only are significant for the daily weather forecast but also are important for energetic calculations of atmospheric processes.

A milestone in monitoring of large-scale cloudiness is the application of weather satellites. With the daily pictures from ESSA 8, estimations of the cloud cover in tenths for geographical 2.5° sections have been made for a period of 3 yr (Dec. 1, 1967–Nov. 30, 1970), and the mean seasonal cloud distribution over Europe and the Atlantic has been calculated.

Twenty-nine synoptic stations have been used for comparison between satellite and surface observations. A detailed discussion shows the reasons for the higher surface values of cloud cover compared to the satellite values. The mean annual differences, with values about 0.9 tenth over northern Europe and 1.5 tenths over southern Europe, are caused by geometric, synoptic, and orographic factors, there is a basic difference of about 0.6 tenth between the two different observation methods.

1. INTRODUCTION

Clouds on the one hand reflect the solar short-wave radiation and influence the albedo directly; on the other hand, they absorb and emit long-wave radiation and play an important part in the radiation budget of the troposphere. Determining the amount of sky covered by clouds and the type of clouds involved is, therefore, one of the main tasks of climatological and synoptic weather stations. Conventional observations are made from the ground—the estimated values include errors of varying magnitude, depending on the experience of the observer, the location of the observation station, and the method of observations (systematic errors). These conventional observations also have the potential error inherent in any system that tries to describe conditions over a large area using point source observations.

The weather satellite represents a major milestone in monitoring large-scale cloud distribution. In addition to amount and type of clouds, one can observe large areas simultaneously and determine directly the daily changes in cloud patterns.

Several authors already have used this new observation method to perform cloud research. Arking (1964), Clapp (1964), Sadler (1969), and others have determined average cloudiness on the basis of nephanalyses (i.e., the diagrammatic representation of satellite photographs published by the U.S. Weather Service). Kornfield and Hasler (1969) and Kornfield et al. (1967) have chosen the approach of using photographic and digital accumulation of satellite data. The *Global Atlas of Relative Cloud Cover* (National Environmental Satellite Service and U.S. Air Force 1971) is also based on this method. One should note that snow-covered areas and extended sand deserts cause certain problems with this method since their values of reflectivity are similar to those of clouds.

2. DATA AND METHOD

This investigation has been performed for the period Dec. 1, 1967–Nov. 30, 1970. It is based primarily on television pictures from the ESSA 8 weather satellite received daily at the Institut für Meteorologie, Berlin.

The observed area extends from 30°N to 70°N and 40°W to 70°E (i.e., it includes northern Africa, the polar region, Greenland, and western Siberia). Because of darkness in the polar region during the winter period, pictures could be taken only as far as 60°N.

Using geographical coordinates, we divided this area into 2.5° sections, for which the daily degree of cloud cover was estimated from satellite pictures by experienced assistants. Even they found it difficult to distinguish between clouds and snow; therefore, we used synoptic cloud and snow observations over the European Continent during the winter season to avoid errors and to obtain additional aid in determining the cloud cover.

3. THE MEAN SEASONAL CLOUD DISTRIBUTION

The highest amount of cloud cover (8/10) in the European-Atlantic region in spring is observed south of Greenland and near the island of Jan Mayen (fig. 1) Beginning in this area, the zone of maximum cloudiness extends across Great Britain, into Germany, and then eastward. An extended relative minimum with values below 5/10 is found over northern Europe. The western part of this minimum is a result of the shadow effect of the Norwegian mountains.

The convection and, consequently, the distribution of clouds are influenced by different conditions of atmospheric stability over the still-cold Baltic Sea and the adjacent already warm continent. Figure 1 gives a clear impression

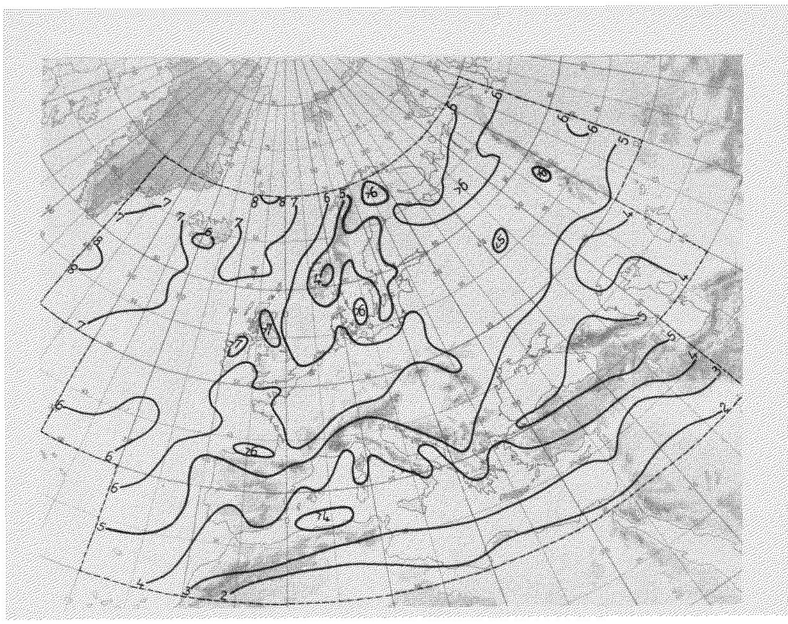

FIGURE 1.—Mean cloud cover in tenths over Europe and the Atlantic in spring.

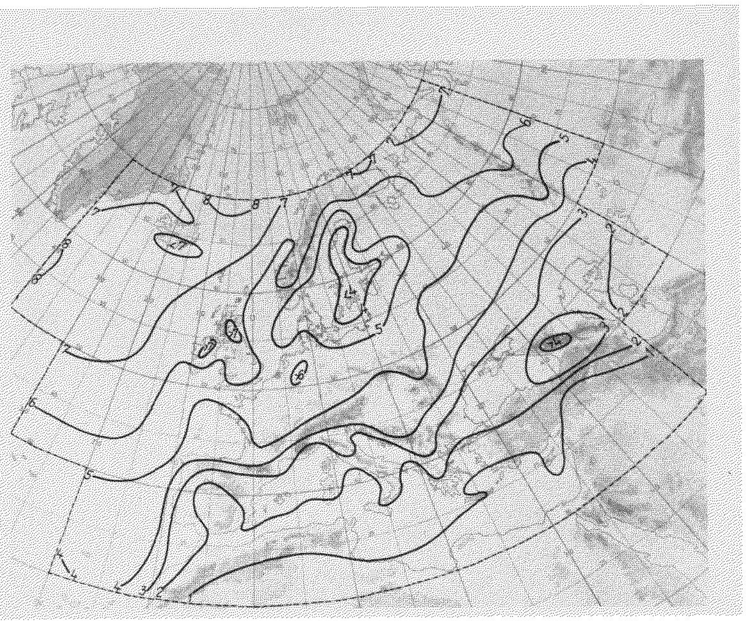

FIGURE 2.—Same as figure 1 for summer.

of the convective influence over northern Europe, the Baltic Sea, Great Britain (maximum greater than 7/10), and over the central Mediterranean where the 4/10 line of cloud cover is practically identical with the coastline.

In the summer season (fig. 2), the large-scale cloud distribution is similar to that in spring. While the values over the Atlantic have increased slightly, there is a decrease of the cloud cover over Europe. This fact becomes obvious in the Mediterranean area. The cloud cover over the Atlantic is a result of intense cyclonic activity and the development of extended stratus and stratocumulus layers, which are caused by the advection of moist, warm air over the cold sea areas.

As in spring, a significant cloud minimum can be seen over the Baltic Sea, the cloud cover following the coastline. The influence of mountains on the distribution of clouds can be recognized easily south of Iceland, over Norway, and at the Ural Mountains.

In fall (fig. 3), the cloudiness increases remarkably, especially over the continent. The minimum over Scandinavia has vanished, and the 6/10 cloud cover line has moved southward over Europe as far as 50° latitude. Maxima with values greater than 8/10 are found northeast of Iceland and over the northern parts of Russia. The Mediterranean, however, remains fair with average values of about 3/10 in the west and 2/10 in the east.

In winter (fig. 4), an extended zone with more than 7/10 mean total cloud cover is situated over parts of western, central, and southeastern Europe. This cover usually consists of extended stratiform cloud layers that frequently have a vertical dimension of only a few hundred meters. The influence of mountains on the cloud distribution becomes evident by the large gradient between the northern and southern parts of the Alps. Another maximum with values higher than 7/10 is found over the Atlantic Ocean east of Greenland. The zone of the Siberian High remains fair; in some parts near the Ural Mountains, the values reach only 4/10. In the Mediterranean area, the cloud cover reaches its greatest intensity in winter with average values exceeding 4/10.

4. SATELLITE OBSERVATIONS VERSUS GROUND-BASED OBSERVATIONS

We now wish to determine how well the preceding cloud observations by satellite agree with conventional observations made from the ground; furthermore, we must determine whether the differences in cloud amount are systematic or nonsystematic. Quantitative comparison is important because it provides a link between the two different observation methods, even for former time periods.

For the comparison between ground and satellite observations, we chose 29 synoptic stations in the European-Atlantic area. Seasonal means of cloudiness were computed (based on ground observations) for these stations in the same manner and for the same time period (Dec 1, 1967–Nov. 30, 1970) as was done previously for satellite observations.

The ESSA 8 satellite photographs of the European-Atlantic region are usually taken around 1100 LST. To keep the time interval small between the moment the satellite picture is taken and the synoptic observation time, we used the calculated cloud cover at 1200 GMT for 18 observation points west of 15°E. For the area east of 15°E, we computed the mean values of ground observations at 0600 GMT and 1200 GMT and compared them with the values obtained from satellite data.

Figure 5 shows the results of the comparison for these 29 synoptic observation points. The values are mean annual differences in cloudiness between ground observation and satellite observation in tenths. We can see that the sign is positive for all stations; that means that the ground observations lead to higher mean values, than the satellite pictures. The deviation values are not equal however. For example, 0.8 tenth are calculated at ship M while values up to 1.6 tenths are obtained at Gibraltar

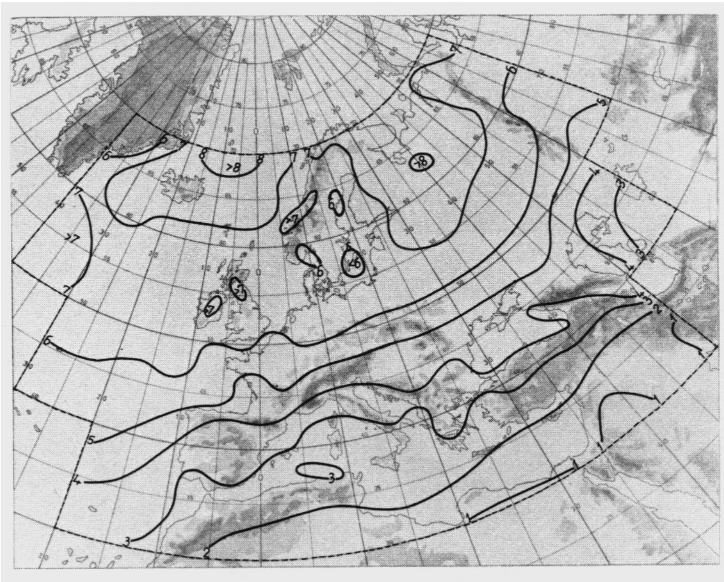

FIGURE 3.—Same as figure 1 for fall.

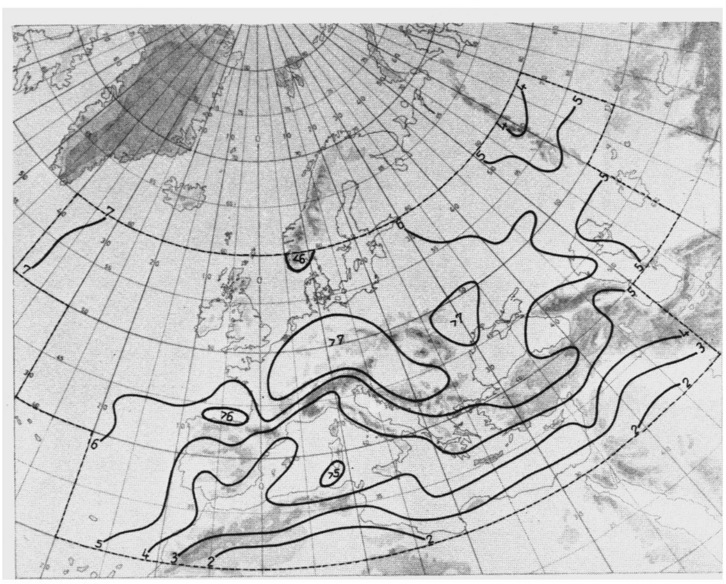

FIGURE 4.—Same as figure 1 for winter.

and around the Mediterranean. The examples demonstrate that the differences in low latitudes are greater than those in higher latitudes.

If we average the values shown in figure 5 for 10° belts, including Ankara, Turkey, in the northern and the Balearic Islands in the southern belt, we find a significant increase of the mean difference of ground observations minus satellite observations in the north-south direction. From table 1, we find a difference of about 0.2 tenth for each 10° belt.

Figure 6 shows the seasonal deviations from the annual mean differences of cloudiness (as seen in fig. 5) for all 29 stations. The variations over the Atlantic, as well as over the continent, are small. They are only slightly larger in the south. Since the seasonal deviations are relatively small in almost 95 percent of all cases, the discussion about differences between ground observations and results of satellite observations can be limited to the annual values given in figure 5.

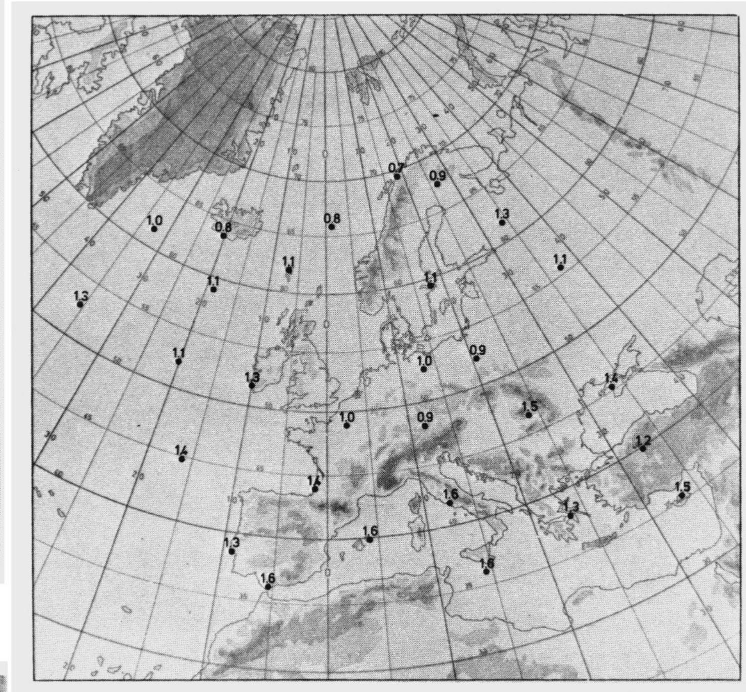

FIGURE 5.—Mean annual differences in cloudiness between ground observation and satellite observation (in tenths).

TABLE 1.—*The mean annual differences in cloudiness between ground observations and satellite observations averaged over 10° latitude belts*

60°–70°N	50°–60°N	40°–50°N	30°–40°N
0. 94	1. 11	1. 30	1. 48

We now should consider the reasons for the different amounts of cloud cover observed by ground observers and by satellite. It is evident that both methods have specific problems, which will be treated shortly.

The curvature of the Earth is of great importance for the cloud observation made from the ground. In the case of low clouds and a small horizontal angle, the openings between clouds cannot be recognized; thus, the evaluation includes a perspective error. This effect leads to ground observations of more cloud cover than actually exists. Figure 7 shows a good example of this effect. In this case, an observer would estimate about 6/8 cloud cover even though there is really only 3/8.

Satellite observation difficulties are caused by technical problems. Since the reflectivity of thin cirrus clouds is small, these clouds are difficult to recognize on satellite pictures. As a result, the mean values of cloud cover—especially over the "gray" continent—appear smaller than they actually are.

Another effect depends on the resolution of the camera system. Since it is limited, the spaces between cumulus clouds cannot be resolved. Instead of single clouds, extended cloud complexes are seen; thus the obtained mean values are too high, mainly over the continent. Since the cirrus effect and the cumulus effect are opposite in satellite observations, the error produced by one effect is partly compensated by the other.

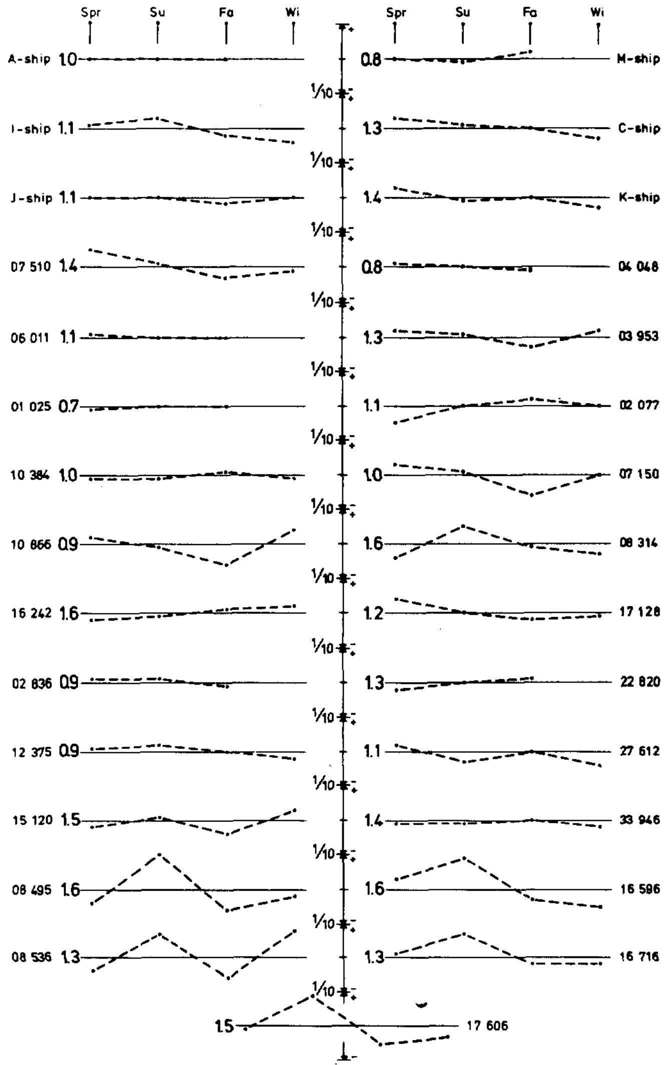

FIGURE 6.—Seasonal deviations from the annual mean differences of cloudiness.

Another important question is that of the representativeness of synoptic point observations for a large area (i.e., geographical 2.5° grids). An example is given in figure 8. The amount of cloud cover reported depends only on the position of the observer in relation to the cloud layer. This leads to observations varying from cloudless to partly cloudy to overcast, whereas the satellite pictures show a cloud cover of only 50 percent.

To determine the representativeness of point observations of clouds for an extended area, one must consider several factors. Figure 9 demonstrates the method for computing the area, A, visible to the observer using the equations

$$r = h \cot \alpha$$

and

$$A = r^2\pi = h^2\pi \cot^2 \alpha.$$

Here, h represents the height of the clouds, and r is the radius. Table 2 gives the values of r and A for different heights, with the zenith angle 90° minus α being assumed as 80°.

Table 3 gives the areas, A_S, of 2.5° grids for the latitudes 30°–70°N. The estimation of cloudiness from satellite pictures has been performed for these areas.

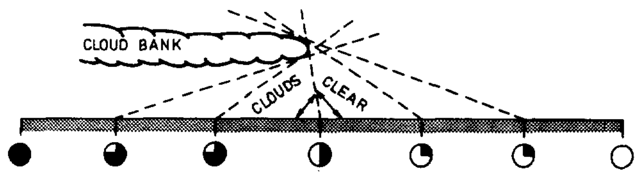

FIGURE 7.—Effect of earth's curvature, causing ground observer to report 6/8 cloud cover, when satellite observes only 3/8.

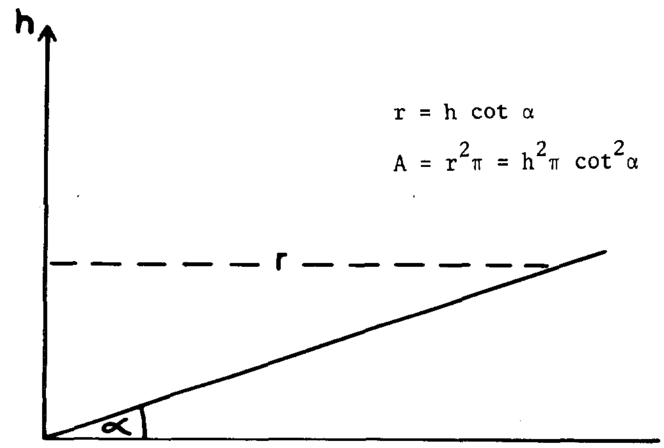

FIGURE 8.—Area visible to a ground observer.

TABLE 2.—*The area* A *and radius* r *visible to an observer for specific cloud heights* h *and* $\alpha = 10°$

h (km)	1	2	4	6	8	10	12
r (km)	5. 7	11. 3	22. 7	34. 0	45. 4	56. 7	68. 1
A (km²)	101	404	1617	3638	6467	10, 105	14, 551

TABLE 3.—*The area* A_S *visible on satellite pictures taken at specific latitudes for 2.5° grids*

Lat. ϕ (°)	30	40	50	60	70
A_S (km²)	66, 965	59, 233	49, 706	38, 661	26, 445

The relation A/A_S shows what part of the 2.5° area can be observed from the ground. Values of A/A_S for different heights of clouds, h, and different latitudes, ϕ, are given in percent in table 4.

It is evident that the part of the 2.5° section observable from the ground depends on the height of clouds as well as on the latitude. In the case of low clouds, the part to be observed is very small; that is, it varies between 0.15 and 0.60 percent at 30° latitude with clouds in a level of 1 to 2 km and between 0.38 and 1.53 percent at 70° latitude. The situation changes in the case of cirrus clouds: at an altitude of 12 km, the value reaches 21.7 percent in the south and 55 percent in the north. Therefore, because of geometric reasons, the synoptic cloud observations for a 2.5° section are less representative in the south than in the north.

The influence of the height of clouds on the representativeness of point observations depends on the synoptic situation (i.e., on the frequency of low-cloud situations).

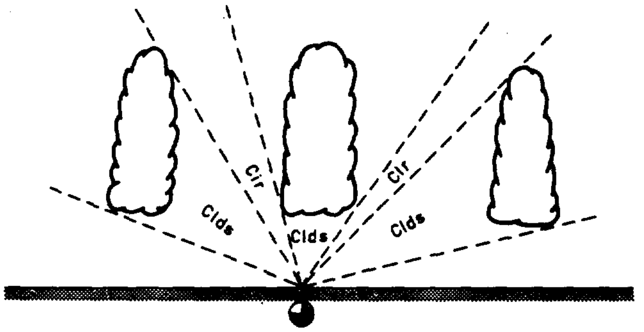

FIGURE 9.—Effect of ground observer position on his reporting of satellite-observed 50 percent cloud cover.

TABLE 4.—*The percentage of the 2.5° satellite-viewed area that can be observed from the ground for different cloud heights,* h(*km*), *and latitudes,* ϕ

$\phi \backslash h$	1	2	4	6	8	10	12
30°	0. 15	0. 60	2. 41	5. 43	9. 66	15. 09	21. 73
40°	. 17	. 68	2. 73	6. 14	10. 92	17. 06	23. 56
50°	. 20	. 81	3. 25	7. 32	13. 01	20. 33	29. 27
60°	. 26	1. 05	4. 18	9. 41	16. 73	26. 14	37. 64
70°	. 38	1. 53	6. 11	13. 76	24. 45	38. 21	55. 02

This factor varies from region to region and from season to season. As can be seen from figure 5, the orographic situation also seems to cause certain differences between the results of the two observation methods. For example, small circulation systems with local peculiarities in the cloud field frequently develop in mountain regions, along the coastline, and over islands; however, they are not representative of the larger area. This effect may explain the higher deviations in the Mediterranean region in summer (fig. 6).

The time interval between ground and satellite observations were neglected in this investigation; we have tried to minimize these differences as much as possible to eliminate the diurnal variation of cloudiness.

3. CONCLUSIONS

In table 1, the differences ΔN show mean values of 0.94 tenth in northern Europe and 1.48 tenths in the south, which means the differences between ground and satellite observations increase toward lower latitudes.

As we recognize in table 1, the increase amounts to 0.18 tenth per 10° latitude. This value is composed of two factors (a) the area increase f_g of the 2.5° sections depending on the latitude and (b) the sum of the other effects f_x (depending on the time difference between ground and satellite observation and the synoptic and orographic situations). Based on the values in table 3, we derive the following percentage values for f_g and its complement f_x.

	70°–60°	60°–50°	50°–40°	40°–30°
f_g (percent)	46	28	19	13
f_x (percent)	54	72	81	87

This means that the influence of the area-increase is large in northern latitudes but small in lower latitudes. On the other hand, the influence of the effect f_x increases from north to south. The increase of f_x toward the south is caused notably by the formation of cumuliform clouds. As an additional study has shown, the mean ratio of cumuliform to stratiform clouds is small in the polar region and large in the south. In summer for example, the ratio is less than 0.15 at 70°N over the Atlantic and about 1.0 in the Mediterranean. Because of the difference in the thermal conditions over land and over ocean, the surface observations from the coastal and island stations cannot be representative for a longer area.

Extrapolating poleward from the value 0.94 tenth in the 60°–70°N zone, using the calculated rate of 0.18 tenth per 10°, we arrive at a basic value R of about 0.6 tenth in the 80°–90°N zone for the difference between ground and satellite observation. Thus for different latitudinal zones, we have

$$\Delta N_g = N_g - N_s = \Sigma f_g + \Sigma f_x + R$$

where $f_g + f_x = 0.18$ tenth per 10° latitude. The relationship now allows a connection between the conventional data of mean cloud cover and the mean cloud distribution based on satellite data in different latitudinal bands even for former periods.

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[*Received May 22, 1973; revised August 29, 1973*]

UDC 551.578.4:551.507.362.2(084.1)(78)"1972.11/12"

PICTURE OF THE MONTH
Autumn Snow Storms in the Plains

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River Forecast Centers (RFC's) and Weather Service Forecast Offices (WSFO's) in the Great Plains States require more detailed snow cover data than can be obtained from standard reporting stations. Early in the season, the RFC acquires initial snowfall reports from their river-rainfall network but receives little subsequent data between snowfalls. Areal coverage and snow depths are important to the WSFO in forecasting temperatures and cloud cover.

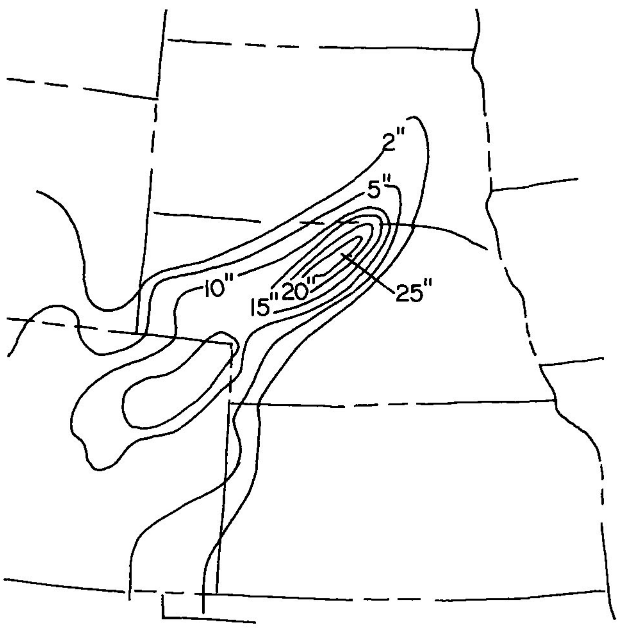

FIGURE 1.—Isopleths of snow depth at 1200 GMT, Nov. 2, 1972.

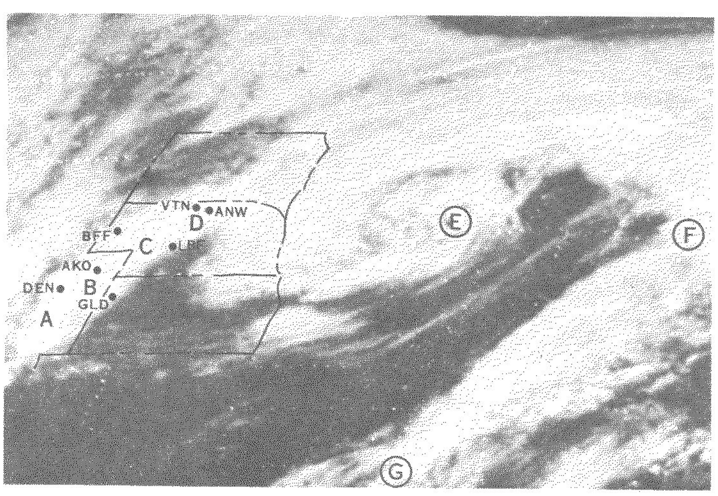

FIGURE 2.—ATS 3 at 1846 GMT, Nov. 2, 1972.

Satellite data from the geostationary Applications Technology Satellite (ATS) 3 spacecraft are being received operationally at the Satellite Field Services Station (SFSS) in Kansas City, Mo. These data can provide additional snow cover information to RFC and National Weather Service forecasters. For example, two interesting snow situations occurred in the Great Plains during the

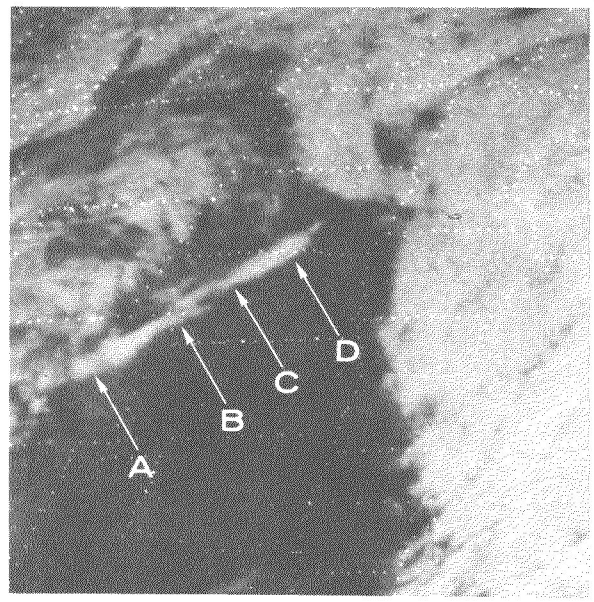

FIGURE 3.—ATS 3 at 1755 GMT, Nov. 7, 1972.

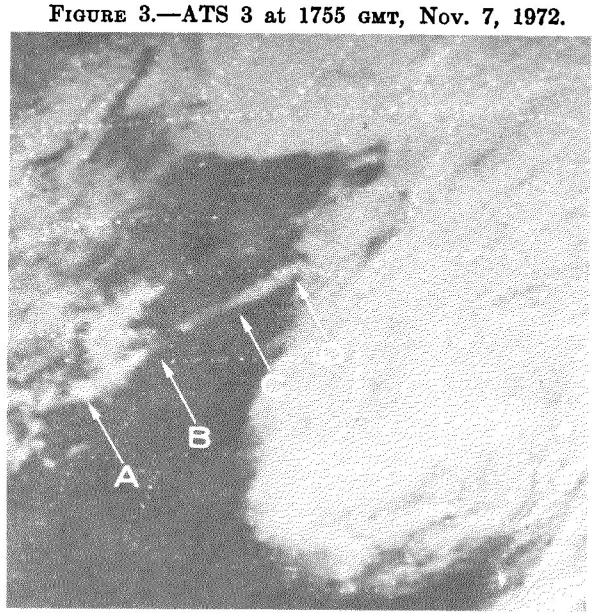

FIGURE 4.—ATS 3 at 1802 GMT, Nov. 10, 1972.

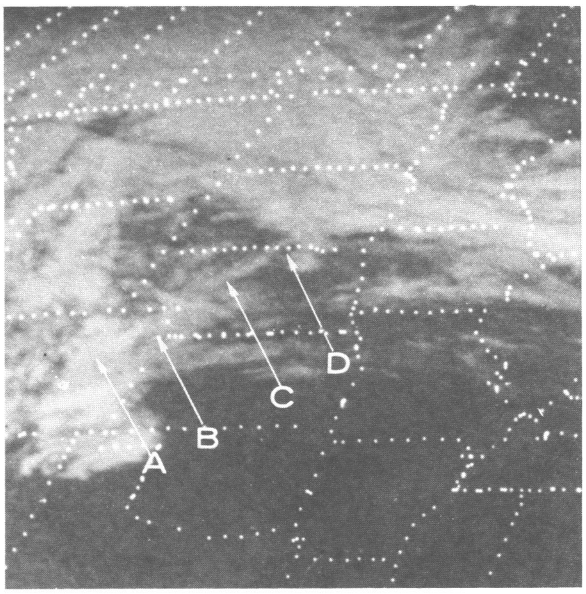

FIGURE 5.—ATS 3 at 1807 GMT, Dec. 1, 1972.

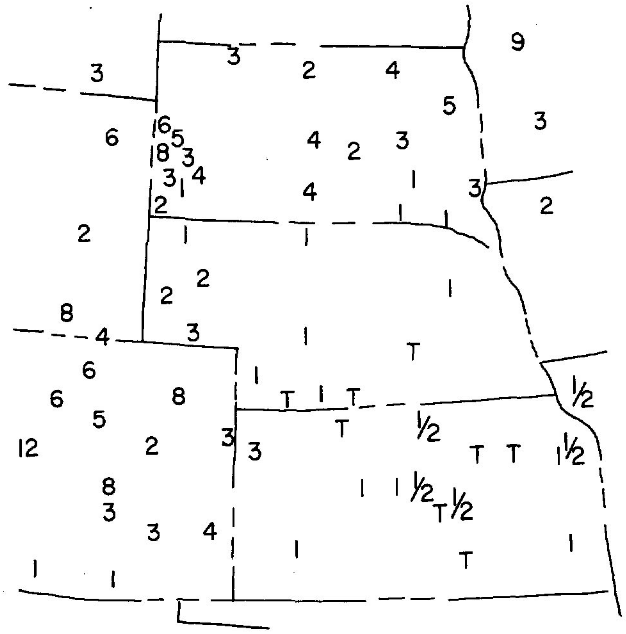

FIGURE 7.—Total snow depth at 1200 GMT, Dec. 6, 1972.

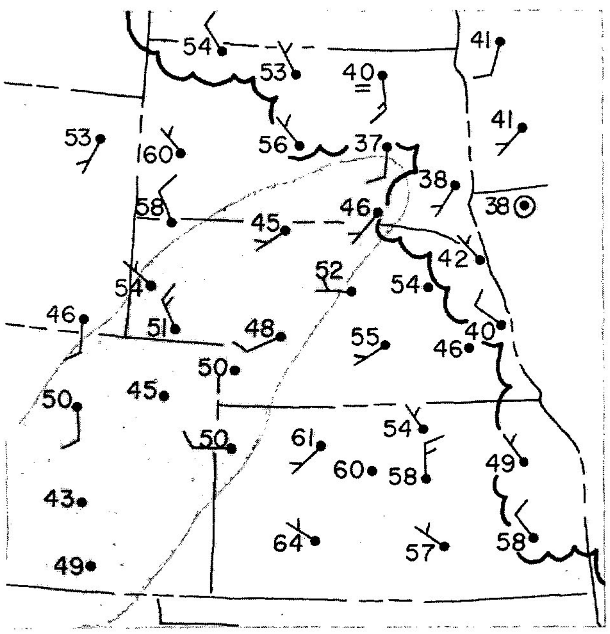

FIGURE 6.—Maximum temperatures ending at 0000 GMT, Nov. 4, 1972, and the 1800 GMT wind field and cloud cover boundary. The shaded area is the extent of snow cover.

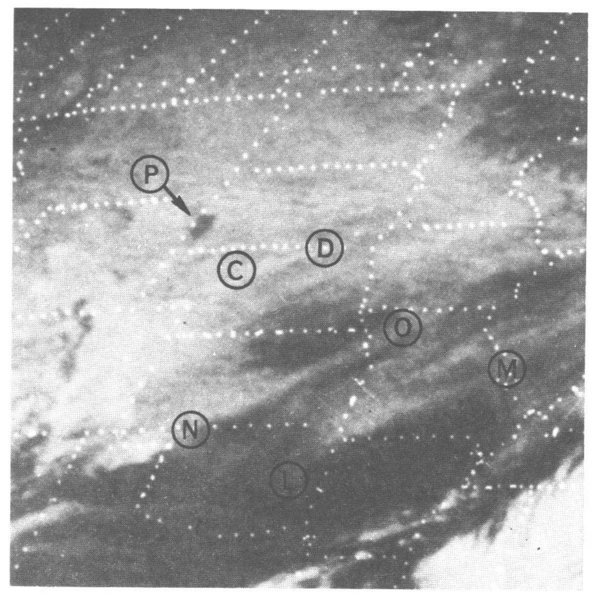

FIGURE 8.—ATS 3 photograph at 1802 GMT, Dec. 6, 1972.

fall of 1972. One produced a typical, narrow but heavy snow band and the other an unusually widespread, but light snow cover.

The first snow resulted from a low-pressure system developing over northwest Kansas on the afternoon of November 1 and moving east-northeast. This system left a narrow band of heavy snow from Colorado to South Dakota. Reported snow depths ranged from 10 to 25 in. (fig. 1). Heaviest amounts were observed in northeast Colorado with Akron (AKO) reporting 19 in. and in north-central Nebraska where Ainsworth (ANW) was blanketed with 25 in. The ATS 3 picture (fig. 2) taken at 1846 GMT on November 2 shows the snow band ABCD with the heaviest snows near B and D. By this time, the cloud vortex (E) associated with the Low was located over the Wisconsin-Illinois border with the surface front (F–G) curving across Lake Erie, central Ohio, and then southwestward into the Gulf States.

In this case, except for a few first-order stations and some river-rainfall observers who reported precipitation over southwest Nebraska and Colorado, the RFC received no additional reports from the heavy snow belt through November. Satellite observations on subsequent cloud-free days (figs. 3–5) enabled the RFC to determine the area of remaining snow cover and added reliability to their snow melt calculations. Most of the large area of snow cover diminished rapidly, but the two areas that received more than 15 in. of snow [northeast Colorado (A–B) and north-central Nebraska (C–D)] remained snow covered through November and into December (figs. 3–5). These satellite observations provided information on the areal snow cover when surface reports were not adequate or were no longer available. In this case, the *NMC Observed Snow Cover Map* for 1200 GMT on both November 10 and December 1 showed Akron, Colo., as the only station reporting snow cover from northeast Colorado through north central Nebraska.

Snow cover can also have a marked effect on temperatures. Figure 6 shows that maximum temperatures in the snow cover area on November 3 averaged 5°–10°F lower than the surrounding area where there was no snow cover and skies were clear.

The second, widespread but light snowfall resulted from as an upper level trough sweeping across the Great Plains on December 5. Snow amounts were generally less than 2 in. (fig. 7). The ATS 3 satellite picture (fig. 8) taken at 1802 GMT shows an unusually large area of snow cover for early December. This snow cover stretches from the Canadian border southward into Oklahoma and Missouri. Note the bands of snow oriented northeast–southwest in Kansas and Missouri (L–M, N–O) indicating areas of varying amounts of snow cover. This pattern shows the path of the convective activity that produced the snow and supplements figure 7 by adding details to the conventional reports.

Three other areas of interest were noted. Gage, Okla. (just south of N, fig. 8), reported 1 in. of snow on the ground. The brightness of the image in the northeast part of the Texas Panhandle (fig. 8) implies a greater snow depth in that area. This was from earlier snowfall. The Black Hills appear as a dark area in the picture (inferring no snow or cloud cover) even though stations throughout the region reported 1–7 in. of snow cover. The coniferous tree cover is sufficiently dense to mask the snow-covered ground and produce this dark image on the satellite picture. The last point of interest is the brighter band C–D in figure 8. This is the remainder of the heavy snow that fell on November 1 and was observed in figures 2–5.

The satellite data discussed here were used by the Kansas City RFC and WSFO on a real-time basis. The data were useful in defining variations in snow depth and providing snow cover information when it was not available through conventional means.

ACKNOWLEDGMENTS

The author would like to thank E. Ferguson, Manager, Kansas City, Mo., Satellite Field Services Station, for his encouragement and consultation while preparing this paper and H. Mondschein, Hydrologist-in-charge, Kansas City, Mo., River Forecast Center, for the use of snowfall charts and discussion of snow-reporting problems.